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Article

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Intensive long-term pumping in the Principal-Lagunera Region aquifer (Mexico) causing heavy impact on groundwater quality

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Abstract

Located in the semi-arid and water-scarce area, Comarca Lagunera is one of the main agricultural and dairy products supplying regions in Mexico. As a consequence of the intensive exploitation of groundwater resources for irrigating purposes over one century, the water table has declined up to 200 meters and developed several cones of depression, aggravating the energy consumption necessary for lifting and distributing the groundwater in the agricultural land. Due to this long-term overdraft pumping, not only the groundwater flow dynamics are constantly changing, but also water quality has deteriorated significantly during the last decades. This study evaluates groundwater dynamics and the evolution of ion element composition and the quality of water from the Principal-Lagunera Region aquifer. Elevated nitrate and sulfate concentrations are ubiquitous near Bermejillo in the northwestern portion. Arsenic concentration exceeds international drinking water recommendations in 80% of the sampled sites and reaches maximum values of up to 349 µg/l in agricultural fields. The distribution of these high values of arsenic overlaps with the location of depression cones. This suggests a geogenic origin of this metalloid.

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Keywords: Aquifer overexploitation; Groundwater chemistry; Arsenic; Comarca Lagunera; Mexico

1. Introduction

Population, renewable water resources and the economy within Mexico show contrasting and contradicting differences. The southeastern portion of this country represents two-thirds of the nation's renewable water but corresponds only to a fifth part of the population and GDP. Meanwhile, the portion which comprehends north, central and northeast Mexico represents four-fifths of the population and GDP; however, it hosts only a third of the nation's available renewable water resources [1].

The semi-arid to arid Principal-Lagunera Region aquifer (~12500 km²), extending between Coahuila and Durango states in central-northern Mexico, is a typical area where intensive agricultural and rapid economic

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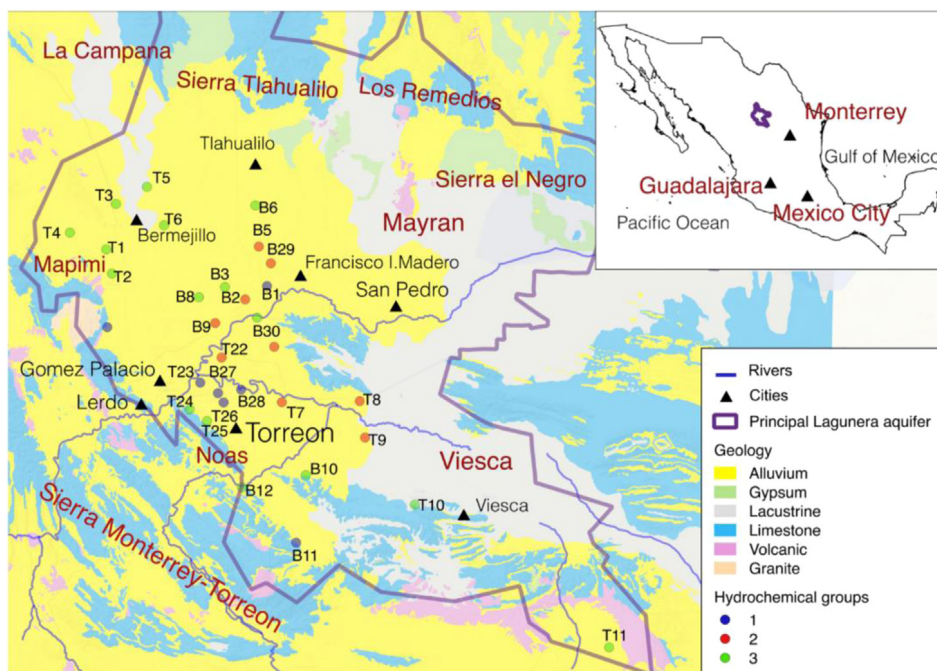


Fig. 1. Study area: (a) location in Mexico; (b) surface geology, sampling points and important geographic features.

development meets with water scarcity (Fig. 1). The cities of Torreón, Gómez Palacio and Lerdo represent the main urban areas, where 70% of the total population lives. Groundwater is the unique source of water supply for these cities and the main source for agribusiness. About 80% of the total withdrawals are used in agricultural fields producing mostly alfalfa, corn and sorghum. Alfalfa is used for intensive livestock operations in the region.

The Principal-Lagunera Region aquifer has been heavily overexploited since the early 1920s. Due to the intensive extraction and pumping technology progress for irrigation purposes, the water levels in wells across the basin dropped yearly by 2–3 m [2–4], increasing exponentially the consumption of electrical energy for the water lifting, supporting the water-energy-food nexus in agriculture [5].

In recent decades, the rapidly growing urban centers have been extracting more water for consumptive use. These cities include Torreón (population ~724,000), Gómez Palacio (~370,000), Lerdo (~160,000) and Matamoros (~118,000), San Pedro (~115,000), Francisco I. Madero (~35,000), Viesca (~25,000) and Tlahualilo (~25,000) [6].

Groundwater quality deterioration commonly results from falling water tables and drilling deeper wells, which access deeper aquifer systems, resulting in two main issues: an increment in energy consumption for the process of water lifting and more mineralized groundwater.

In 1958 arsenic was reported first time in drinking water in the Lagunera area by Cebrian et al. [7] and since then the arsenic became the most commonly studied topic for this area. A recent study shows 5 mg/l arsenic concentration in groundwater of the Viesca aquitard and explains it by evaporation processes throughout the Principal Lagunera Region [4].

The objectives of this study are to (1) assess water table configuration changes of the Principal-Lagunera Region aquifer over the last 100 years; (2) evaluate groundwater chemistry across the aquifer in 2018; (3) deduce the impact of the intensively pumped agricultural basin on groundwater quality.

2. Study area and methods

2.1. Study area

The Principal-Lagunera Region aquifer is part of the Nazas and Aguanaval river basin. It is an inter-mountain basin lying between the physiographical provinces of the Sierra Madre Occidental and Northern Ranges and Plains.

The Principal-Lagunera Region sub-basin is surrounded in the south and southwest by the Monterrey-Torreón and Noas mountain ranges, Mapimí range in the west, all composed of limestone, dolomite and conglomerates, in the east by the ancient lakes Viesca and Mayrán, and in the north by a series of limestone ranges called Sierra La Campana, Sierra Tlahualilo, Sierra Los Remedios and Sierra El Negro (Fig. 1). The basin floor is covered by alluvial deposits containing sand, gravel and conglomerate, lacustrine sediments and gypsum.

The relief across the sub-basin is 2650 m, with the highest mountains reaching 3700 m above sea level (asl) and the basin plain lying at 1050 m asl. The climate is arid to semiarid, with cold winters and low precipitations in summer [8]. The mean annual temperature, precipitation and evaporation potential is 21.3 °C, 260 mm and 2500 mm, respectively [1]. Most of the precipitation occurs between July and September. The vegetation is represented by scrubland and salt-tolerant plants of desert type.

Two types of aquifer units are known in the Principal Lagunera region: the first one consists of granular sediments, and the second one is constituted mainly by calcareous sedimentary rocks and in minor proportion by igneous rocks [1]. Both aquifer units are heterogeneous and unconfined. In addition, alluvial sedimentation of the ancient lakes Viesca and Mayrán formed a lacustrine aquitard in the eastern and southeastern part of the study area.

2.2. Methods

Historical groundwater levels were evaluated by revising earlier studies and generating spatial water table distributions for 1975 and 2015. Changes across the basin were identified in a general context. Water samples from 32 production wells were collected in November 2018 and analyzed for their chemical composition. Samples were collected in HDPE bottles and temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) were measured in the field using portable meters. Alkalinity was determined onsite by acid titration until the endpoint of pH 4.3 in filtered water samples. The samples for silica and cation analyses were acidified with ultrapure HCl to pH < 2 in order to prevent major element precipitation and adsorption during transportation and storage.

The concentrations of dissolved major cations were measured by inductively coupled plasma optical emission spectrometry (ICP-OES) using an Agilent Axial ICP Optical Emission Spectrometer. Major anions were determined and quantified by ion chromatography in un-acidified samples using a Dionex DX-120 equipment. Arsenic was determined by inductive-coupled plasma mass spectrometry (ICP-MS).

Auxiliary parameters and ion concentrations were log-transformed and used in hierarchical cluster analysis using Ward linkage rule for classifying samples with similar characteristics. A one-way ANOVA test was performed in order to establish significant differences among these clustered groups. A varimax rotation was selected in factor analysis for analyzing the relationship between measured variables. A correlation analysis was applied to determine the degree of relationship between two hydrochemical parameters.

3. Results and discussion

3.1. Groundwater table modification

In the 19th century, drinking and irrigation water were obtained from dug wells with a typical depth of tens of meters. At that time, the groundwater table was close to the surface. Starting in the 1950s, the dug wells were replaced by modern production wells for irrigation fields. Nowadays, production wells used for irrigation, municipal water supply and industry are typically installed in alluvium or sedimentary rocks at depths ranging from 50 to 500 m.

According to official information, in 2002, the number of production wells and total abstraction was 2350 and 1088 million m³/year, respectively, while in 2018, these numbers were ascending to 3669 and 1577 million of m³, correspondingly [9]. In other aspects, the Nazas river was lined in 1960 which has reduced groundwater recharge below the river bed drastically. Hence, the combined long-term increase of abstraction and reduction of infiltration led to dramatic groundwater level drops during the last decades [10]. For example, at the beginning of the 20th century, the groundwater table around Torreon city was in the order of 1120 m asl, in 1975 about 1050 m asl, in 2015 about 950 m asl, representing a total drawdown of 170 m so far (Fig. 2).

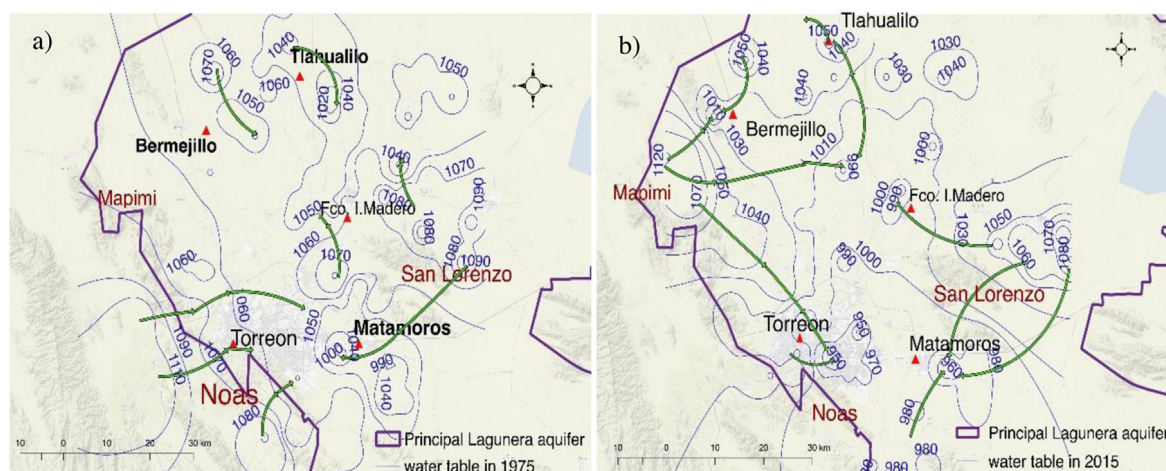


Fig. 2. Groundwater table configuration of the Principal-Lagunera Region aquifer in 1975 (a) and 2015 (b).

Early studies report cones of depression near the cities Torreon, Tlahualilo, Matamoros and Bermejillo as a result of the heavy urban extraction [10,11]. The increasing abstraction in the central part of the area has caused several changes in the flow directions. A general concentric flow starts from the northern mountains and former alluvial lakes till the south of San Lorenzo mountain. The second major flow used to come from the southwestern mountain range and reach the center of the valley running through the cities Torreon and Bermejillo. A piezometric level comparison between the years 1975 and 2015 (Fig. 2) shows that the vadose zone has shortened till the cities Torreón (difference ~ 100 m) and Bermejillo (~ 55 m), and both major flows concentrate groundwater in the abatement cones of these locations. Besides the changes in other cities, Matamoros (40 m–50 m) and Francisco I. Madero (~ 45 m), several cones of depression appeared in an agricultural area between Francisco I. Madero and Tlahualilo reaching 970–990 m asl in 2015.

On the other hand, not only ranges from the southwestern border such as in Sierra Mapimí (2000 m asl) or Sierra Noas (1500 m asl) and from ancient lakes Mayrán and Viesca in the east contribute to the recharge formation, but also San Lorenzo Mountain (1400 m asl) inside the basin adds significant groundwater flux as a result of the increased abatement dynamics in the cities Torreón and Bermejillo (Fig. 2b).

In order to reduce this rapid water depletion, it is necessary to carry out smart innovations in water-saving irrigation methods using sprinkler irrigation and drip irrigation [12,13]. Therefore, it could have a significant reduction in water consumption, in the amount of water pumped, in the overdraft of groundwater, and thus reducing the energy consumption.

3.2. Hydrochemistry

Groundwater in Principal aquifer is slightly alkaline water with a temperature ranging from 23 to 33.6 °C. The TDS widely varies between 190 mg/l and 3894 mg/l with a mean value of 884 mg/l. Three water groups were identified using a hierarchical cluster analysis: Group 1 represents freshwater that is located close to recharge zone of the southwestern limestone mountains, Group 2 denotes low mineralized but highly mixed water, and Group 3 depicts brackish water, located in the gypsum valley where Quaternary lakes used to cover these regions (Fig. 1).

The dominant cations of the aquifer were determined as $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$. Na and Ca concentrations vary from 22 to 969 and from 10.1 to 591 mg/l, respectively. The abundance of the major anions were $\text{SO}_4^{2-} > \text{HCO}_3^- > \text{NO}_3^- > \text{Cl}^- > \text{F}^-$. SO_4^{2-} and HCO_3^- were the dominant ions in the study area ranging from 32.1 to 2850 mg/l and from 86 to 230 mg/l, confirming that the hydrochemical water facies undergo water–rock interactions with carbonates and evaporitic sediments (Fig. 3). The Ca–Na SO_4 type of water refers to the more mineralized Group 3 that is located in the northwest of the study area. The abundance of Ca^{2+} and SO_4^{2-} ions in the northwest is most likely a result of water–rock interaction in zones rich in gypsum (Fig. 3c). The Na release and mix with

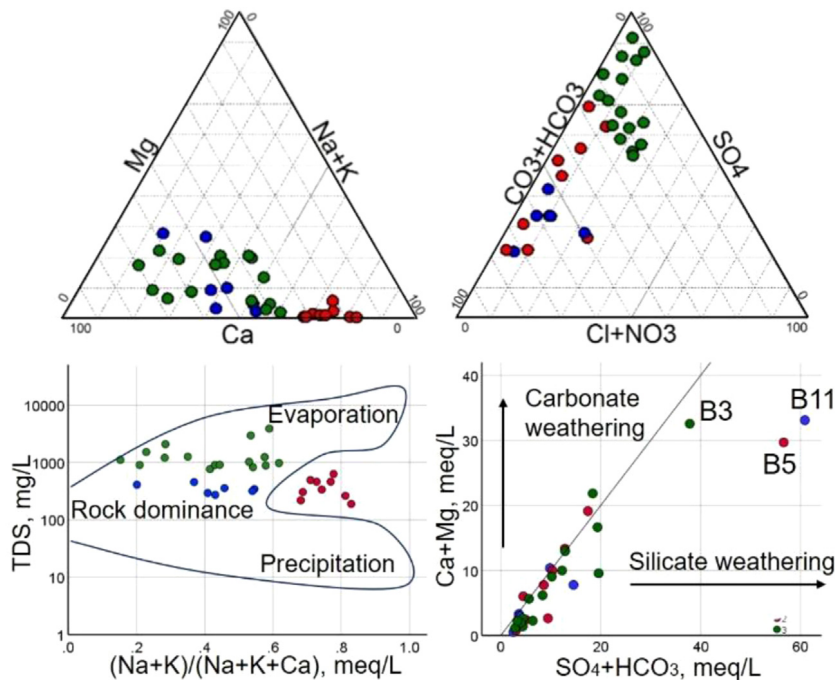


Fig. 3. (a) Piper diagram; (b) Gibb's diagram; (c) $\text{SO}_4 + \text{HCO}_3$ vs. $\text{Ca} + \text{Mg}$.

Ca-SO_4 water could be related to progressive evaporation and ion exchange processes [4]. Therefore, sampling site T4 was classified as a mixed type on the Piper diagram, which could be a result of Ca-SO_4 waters mixing with Na-SO_4 waters (Fig. 1), where a depression cone developed during four decades.

As the second and short flow moves from the limestone and silicate rocks of Torreón-Monterrey Sierra in the southwest and San Lorenzo Mountain in the center, it brings low mineralized and Ca-Na-HCO_3 type of water towards Torreón city and to the western flank of the mountains. The same limestone dissolution process happens in two wells (B7, B11), which are situated directly on the southern mountain. While the north of Torreón city receives carbonate water from the San Lorenzo Mountain, the southern part (T24, T25) could be related to a number of deep cones of depression reaching up to 880 m asl and dissolving deeper gypsum layers of the Gloria Formation from the Later Jurassic period.

Some chemical parameters of water quality were analyzed according to their geographical distribution. The highest values of SO_4 and NO_3 in the aquifer (2800 mg/l and 108 mg/l respectively) were located in the northwestern part near Bermejillo (T3, T5) in alluvial settings where the groundwater flow is indicating modern water in close contact to anthropogenic activities. On the other hand, it is remarkable that 80% of all samples exceed the maximum limit of As concentration in drinking water as defined by WHO (10 $\mu\text{g/l}$), ranging from 5 $\mu\text{g/l}$ to 349 $\mu\text{g/l}$. Highest As concentrations in the aquifer coincide with elevated temperatures above 30 °C in cones of depression in the agricultural lands of the Matamoros and Francisco I. Madero zones (T7, T8, and B9). Principal component analysis and a correlation matrix confirm a positive correlation between As, F and temperature. This shows that As concentrations are probably related to deeper aquifer layers. However, from our data it appears that there is no evident relationship between groundwater level or temperature with the concentrations of As and F. According to a review on As studies [14], there are different potential sources and processes releasing arsenic in Comarca Lagunera, including hydrothermal fluids, arsenic-bearing minerals (arsenopyrite) or oxidation of sulfides.

4. Conclusion

The overdraft pumping from several thousands of irrigation and urban wells in the Principal aquifer is generating profound impacts on the inter-montane aquifer system. The differential decline of the water table created a large number of cones of depressions modifying the original southwest-northeast groundwater flow to concentric

groundwater flow from recharge areas to these abatement cones. The rapid groundwater level drop in Torreón city is remarkable, making evident wrong water management strategies and the need for modernization in agriculture systems improving efficient irrigation, reducing water and energy consumption. Groundwater chemistry is not only ascribed to water–rock interactions and anthropogenic activities occurring at the surface. Other processes may be present. The high NO_3 , SO_4 and As concentrations exceeding international drinking water recommendations are becoming a serious public health and environmental concern. Further studies on contaminant sources and processes in groundwater are highly relevant in order to protect and manage groundwater resources properly.

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References

- [1] CONAGUA (Comisión Nacional del Agua). Determinación de la disponibilidad de agua en el acuífero Principal-Región Lagunera. Mexico City: Estado de Coahuila Diario Oficial de la Federación; 2015.
- [2] CONAGUA (Comisión Nacional del Agua). Estadísticas del agua en México. Mexico city: Secretaría de Medio Ambiente y Recursos Naturales; 2018.
- [3] Aparicio González, Juan Carlos. Estudio geohidrológico del acuífero Principal de la Comarca Lagunera, estados Durango y Coahuila (MSc thesis), Mexico city: Instituto Politécnico Nacional; 2018.
- [4] Ortega-Guerrero Adrián. Evaporative concentration of arsenic in groundwater: health and environmental implications, La Laguna Region, Mexico. *Environ Geochem Health* 2017;39(5):987–1003. <http://dx.doi.org/10.1007/s10653-016-9866-5>.
- [5] Smidt Samuel J, Haacker Erin MK, Kendall Anthony D, Deines Jillian M, Pei Lisi, Cotterman Kayla A, Li Haoyang, Liu Xiao, Basso Bruno, Hyndman David W. Complex water management in modern agriculture: Trends in water-energy-food nexus over the High Plains Aquifer. *Sci Total Environ* 2019;566–577:988–1001. <http://dx.doi.org/10.1016/j.scitotenv.2016.05.127>.
- [6] CONAPO (Consejo Nacional de Población). Proyecciones de la población de México 2010-2050. Mexico city: Secretaría de Gobernación; 2012.
- [7] Cebrian Mariano, Albores, Arnulfo, Aguilar, Manuel, Blakely, Enrique. Chronic arsenic poisoning in the North of Mexico. *Human Toxicology* 1983;2(1):121–33.
- [8] Köppen Wladimir. The thermal zones of the Earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world. *Meteorol Z* 2011;20(3):351–60. <http://dx.doi.org/10.1127/0941-2948/2011/105>.
- [9] DOF (Diario Oficial de la Federación). Disponibilidad media anual de agua subterránea de los 653 acuíferos de los Estados Unidos Mexicanos. 2018, Retrieved from http://www.dof.gob.mx/nota_detalle.php?codigo=5510042&fecha=04/01/2018.
- [10] Boochs Peter, Billib, Max, Aparicio, Javier, Gutierrez. Groundwater contamination with arsenic, region lagunera Mexico. In: 5th International congress on arsenic in the environment. Buenos Aires; 2014.
- [11] Brouste Laurent, Marlin, Christelle, Laurent Dever. Geochemistry and residence time estimation of groundwater from the upper aquifer of the Chihuahua desert (Comarca Lagunera, Northern Mexico). *Appl Geochem* 1997;12(6):775–86. [http://dx.doi.org/10.1016/S0883-2927\(97\)00034-6](http://dx.doi.org/10.1016/S0883-2927(97)00034-6).
- [12] Yahyaoui Imene, Tadeo, Fernando, Vieira Segatto Marcello. Energy and water management for drip-irrigation of tomatoes in a semi-arid district. *Agric Water Manag* 2017;183:4–15. <http://dx.doi.org/10.1016/j.agwat.2016.08.003>.
- [13] Juárez-Hernández Sergio, Sheinbaum Pardo Claudia. Irrigation energy use and related greenhouse gas emissions of maize production in México. *Int J Water Resour Dev* 2019;35(4):701–23. <http://dx.doi.org/10.1080/07900627.2018.1482739>.
- [14] Armienta María Aurora, Segovia, Nancy. Arsenic and fluoride in the groundwater of Mexico. *Environ Geochem Health* 2008;30(4):345–53. <http://dx.doi.org/10.1007/s10653-008-9167-8>.